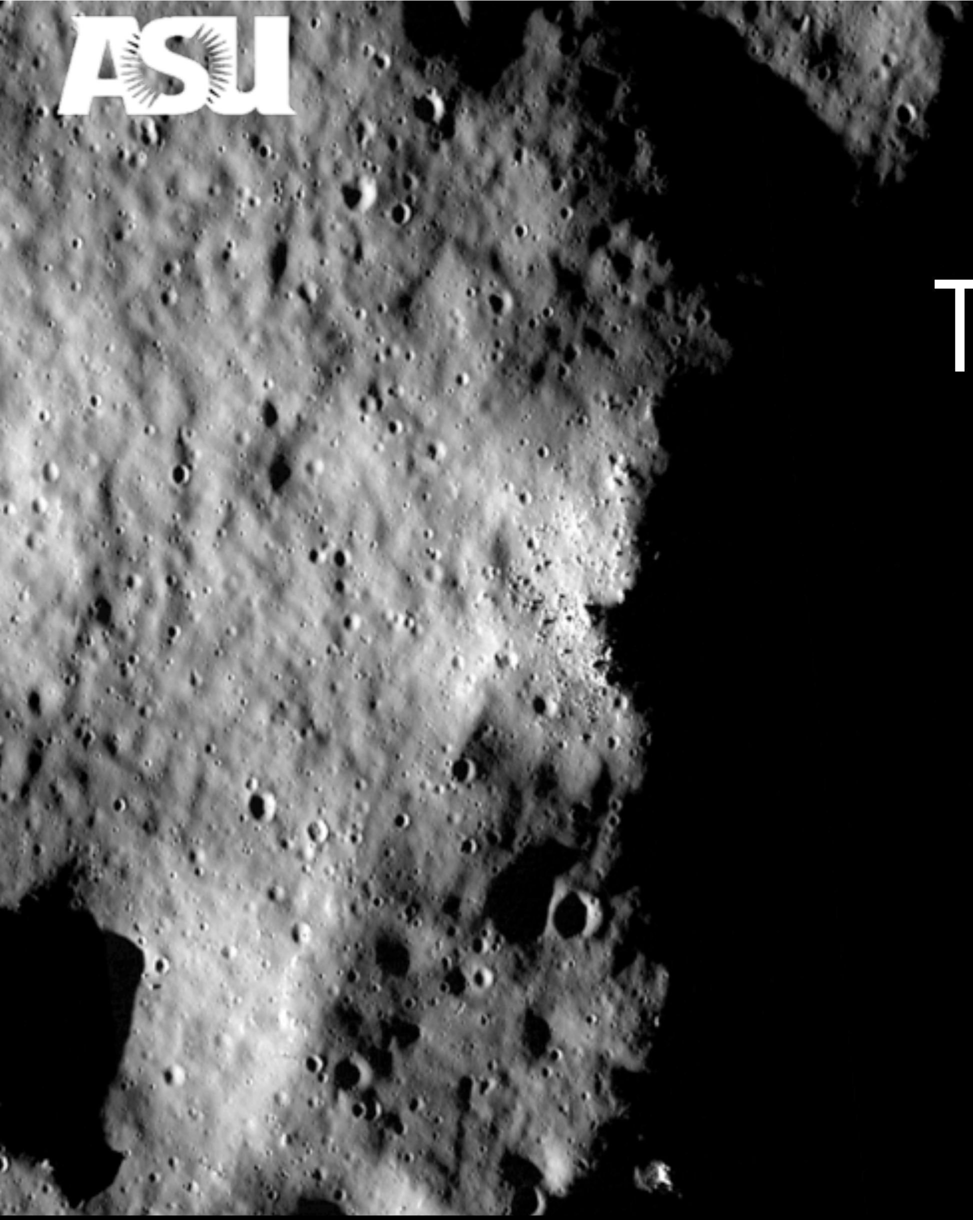


The Lunar polar Hydrogen Mapper (LunaH-Map) Mission

Revealing Hydrogen Distributions at the Moon's South Pole with a 6U CubeSat

Pronunciation: /ˈluːnə/ /mæp/ 'lOOna-map'

"The H is silent because the hydrogen is hiding in the permanently shadowed regions"

PI: Craig Hardgrove
(Arizona State University, School of Earth and Space Exploration)
craig.hardgrove@asu.edu

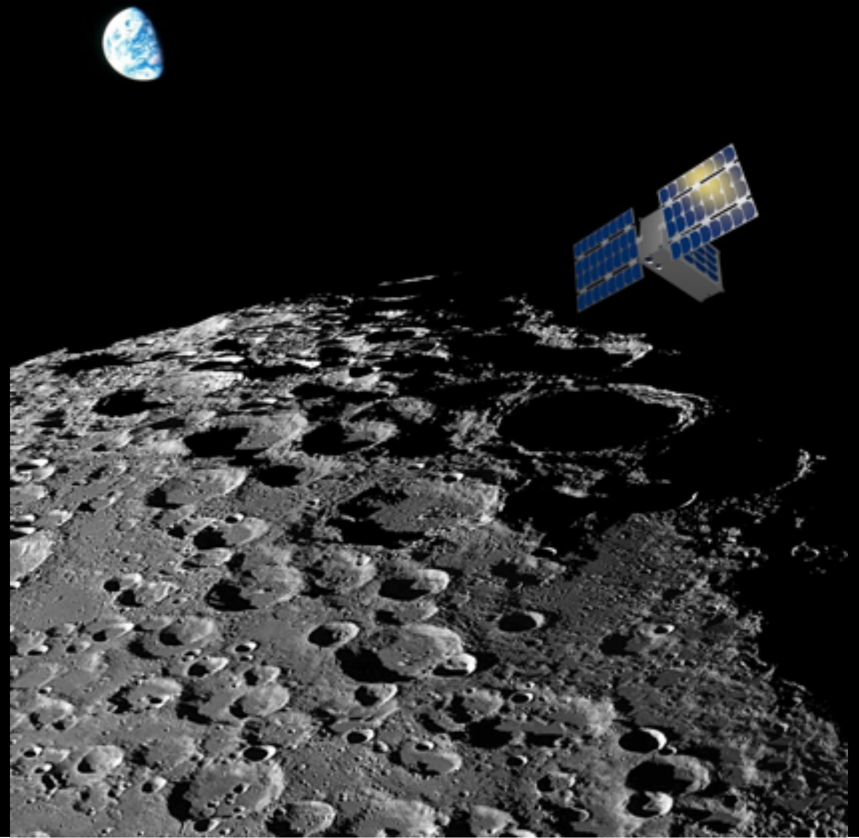
Outline

1. Mission Overview

2. Science Goals

3. Mission & Spacecraft Design

4. Project Status



1. Mission Overview

The LunaH-Map Mission

SIMPLEx

- Small, Innovative Missions for PLanetary Exploration Proposal Program from NASA Science Mission Directorate (SMD) ROSES 2015

- Science Goals: Must be responsive to *2014 NASA Science Plan*
  - *LunaH-Map is responsive to 2014 NASA Science Plan, LEAG Strategic Knowledge Gaps, and NASA Decadal Survey*
    - LEAG Strategic Knowledge Gap 1D, to "understand the quantity and distribution of H species in lunar cold traps," as well as to "determine lateral and vertical distribution of polar volatiles."
    - Planetary Decadal Survey goals to "determine the volatile budgets on surfaces of the inner planets and to determine the composition, distribution and sources of planetary polar volatiles."

Mission Overview

- One of two SMD CubeSats selected in late August 2015 from the first NASA SMD SIMPLEx call ($5.6M program cap).

- Mission is led by ASU who currently serves as primary stakeholder with oversight from NASA Program Executive (Gordon Johnson) and MSFC Planetary Missions Program Office (Rick Turner).

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Mission Overview

- The LunaH-Map PI and the team mutually agree upon acceptable science and engineering goals for the mission that are consistent with the proposed mission goals
  - SIMPLEx missions are science-driven and respond to a variety of NASA strategic goals (NASA Decadal Survey, LEAG Strategic Knowledge Gaps, NASA Science Plan)
    - *LunaH-Map will study the abundance and heterogeneity of lunar polar volatiles within permanently shadowed craters using a compact neutron spectrometer*

  - Expectations and desired outcomes of the mission must be fluid in order to be compatible with multiple new technologies developed in parallel. These include the SLS launch vehicle, propulsion system, radio, and science payload. In addition the mission budget, schedule constraints, requirements from the launch vehicle, and a very small spacecraft development team require a flexible mission approach
    - There is NO currently existing NASA "mission class" (A-D) for LunaH-Map

Mission Objectives (Overall)

Technology Demonstration

- Design, build, fly and acquire in-flight data with a CubeSat-sized neutron spectrometer (Mini-NS)
- Demonstrate a modified e-Hawk solar array design in-flight
- Maneuver using a low-thrust ion propulsion system (for ~8 months) to enter a lunar polar orbit
- Demonstrate scheduled communications, tracking, and spacecraft operations with an interplanetary CubeSat

Science

- Evaluate uniformity of hydrogen across the lunar south pole
  - Map hydrogen abundances of no less than 0.6% WEH (600 ppm) +/- 120 ppm
  - Map hydrogen abundances at spatial scales of less than or equal to 15 square-km

2. Science

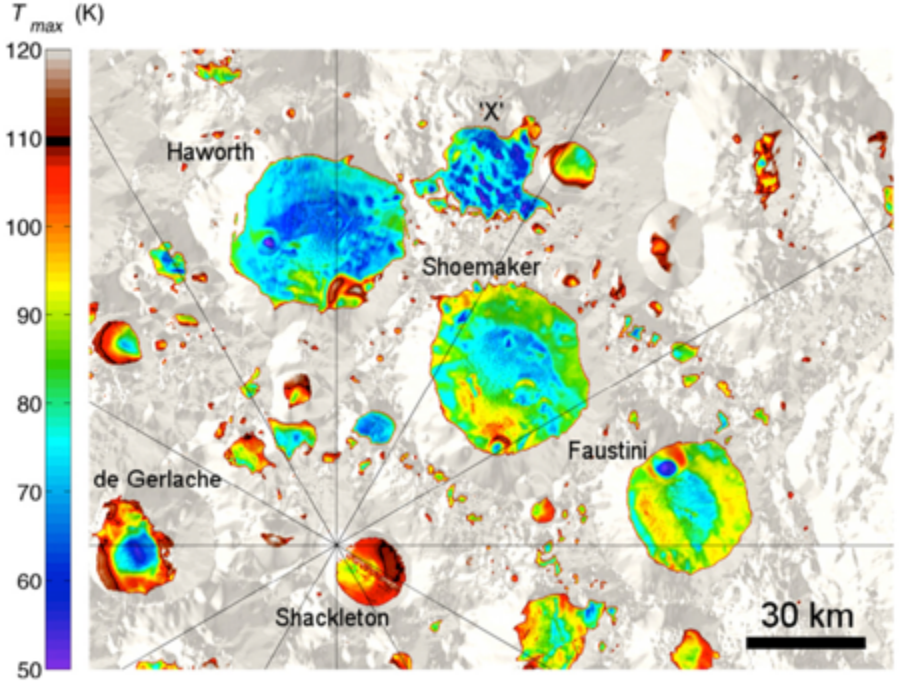
The LunaH-Map Mission

Science Goals

Evaluate and constrain uniformity of bulk hydrogen abundance at the lunar south pole

- "Improved constraints on lunar volatile composition could help identify possible origins, including comet and asteroid impacts, solar wind ion implantation, and outgassing of primordial volatiles from the lunar interior. Although temperatures are perennially below the 110-K threshold to cold-trap water ice over vast regions near the lunar poles *(Paige et al., 2010a)*, the rates of supply, burial, excavation, and destruction are not known."
  (Hayne et al., 2009; Arnold, 1979)

- Observations and models of LPNS neutron data may be consistent with "patchy" hydrogen distributions (above 600 ppm) in permanently shadowed regions *(Elphic et al., 2007; Eke et al., 2009; Teodoro et al., 2010)*



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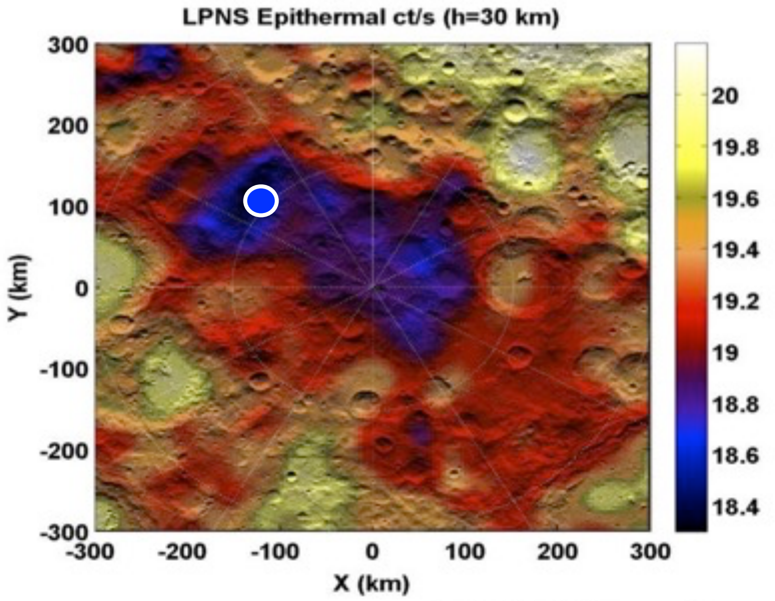
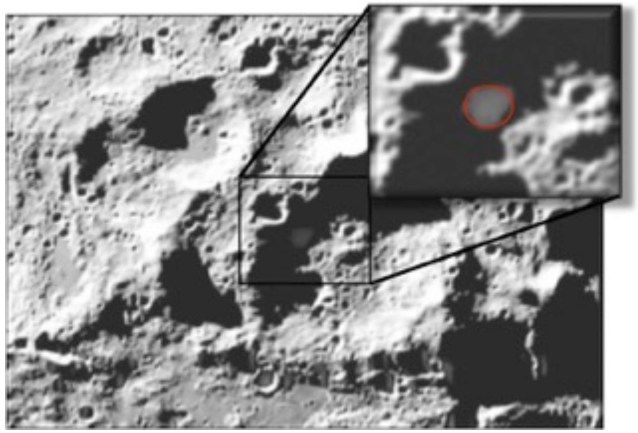
Science Background

- LCROSS measured ~5 wt.% (5000 ppm) water in ejecta cloud formed by an impact into Cabeus crater *(Colaprete et al., 2006)*

- The water equivalent hydrogen seen by LPNS (at spatial scales of ~30-70 km^2) is only about 0.2% (200 ppm) at the LCROSS impact site, assuming the hydrogen is uniformly distributed

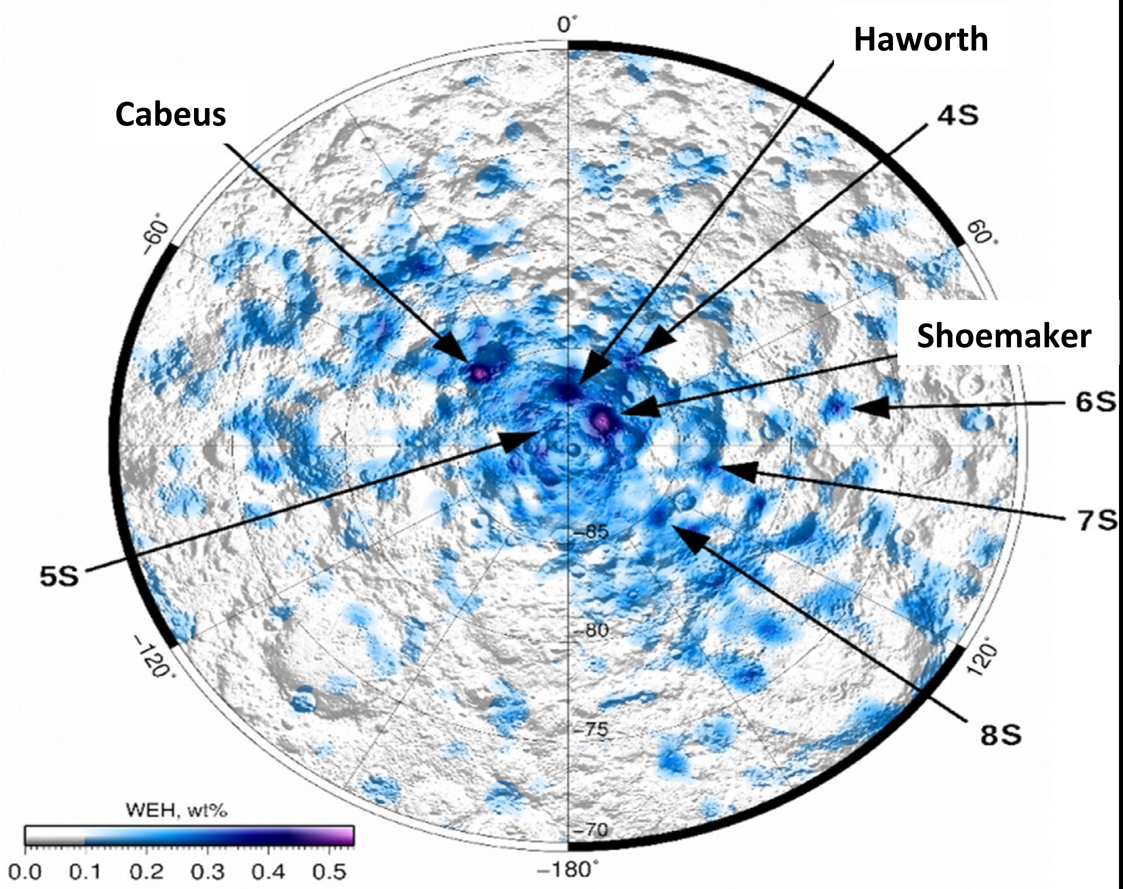
- How does one reconcile the difference?
    - Hydrogen is not uniformly distributed



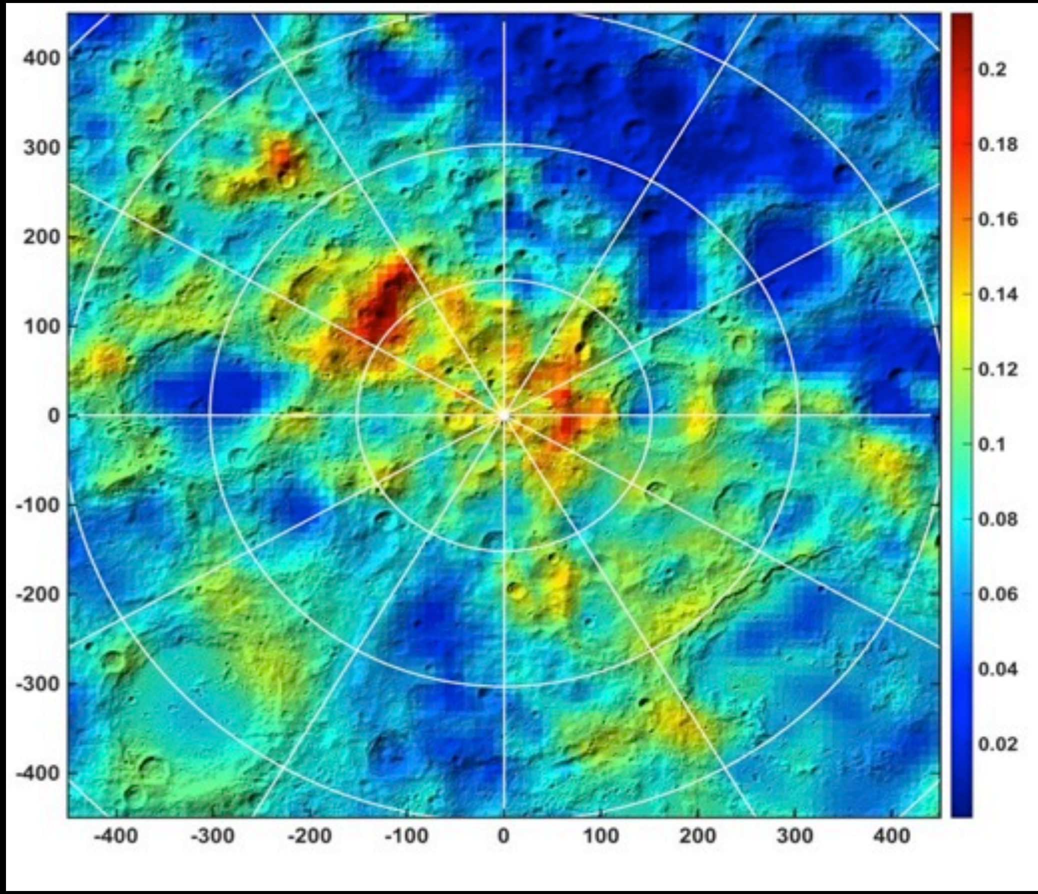


LEND and LPNS Results

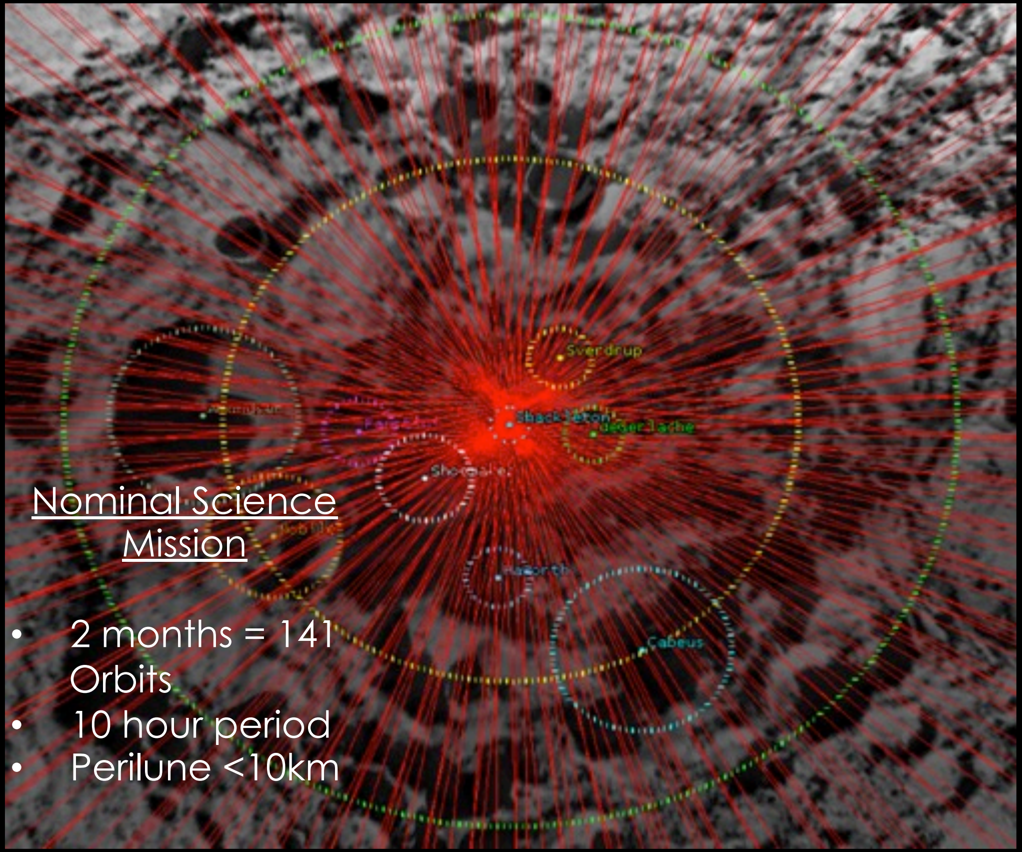
LEND CSETN South Pole
WEH, wt%
(Sanin et al. 2016)



LPNS Adaptive Smooth
Water-equiv. Hydrogen (wt%)
(Elphic et al., 2007)



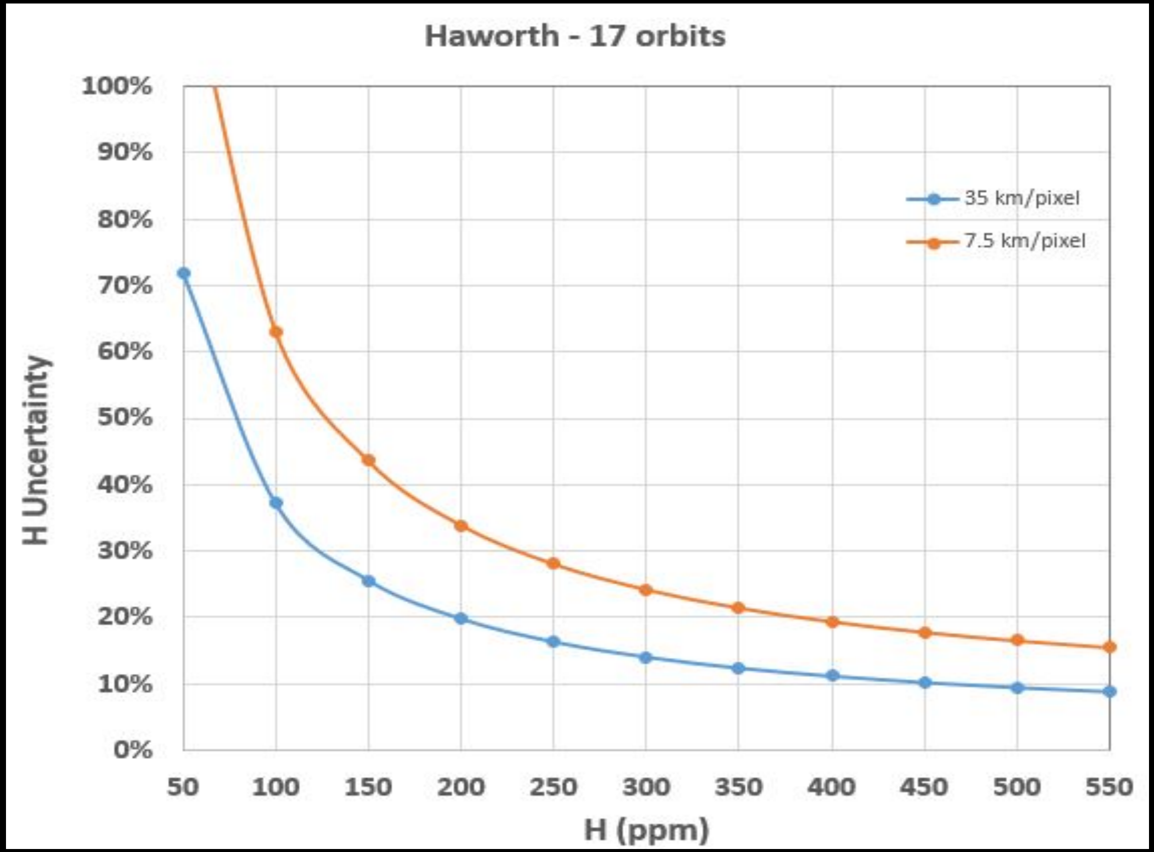
LunaH-Map Science Phase



<u>Nominal Science Mission</u>

- 2 months = 141 Orbits
- 10 hour period
- Perilune <10km

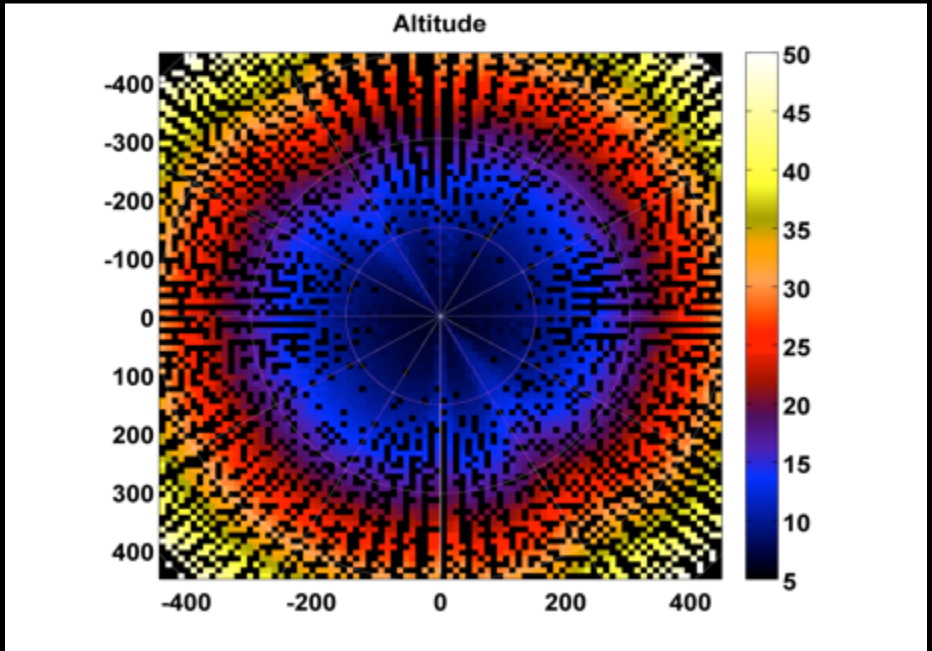
LunaH-Map Science Phase Orbit Tracks



Preliminary Independent Science Phase Comparison of Lunar Prospector Neutron Spectrometer (LPNS) with LunaH-Map* (assumes 100cm^2 detector array)

Important Notes:

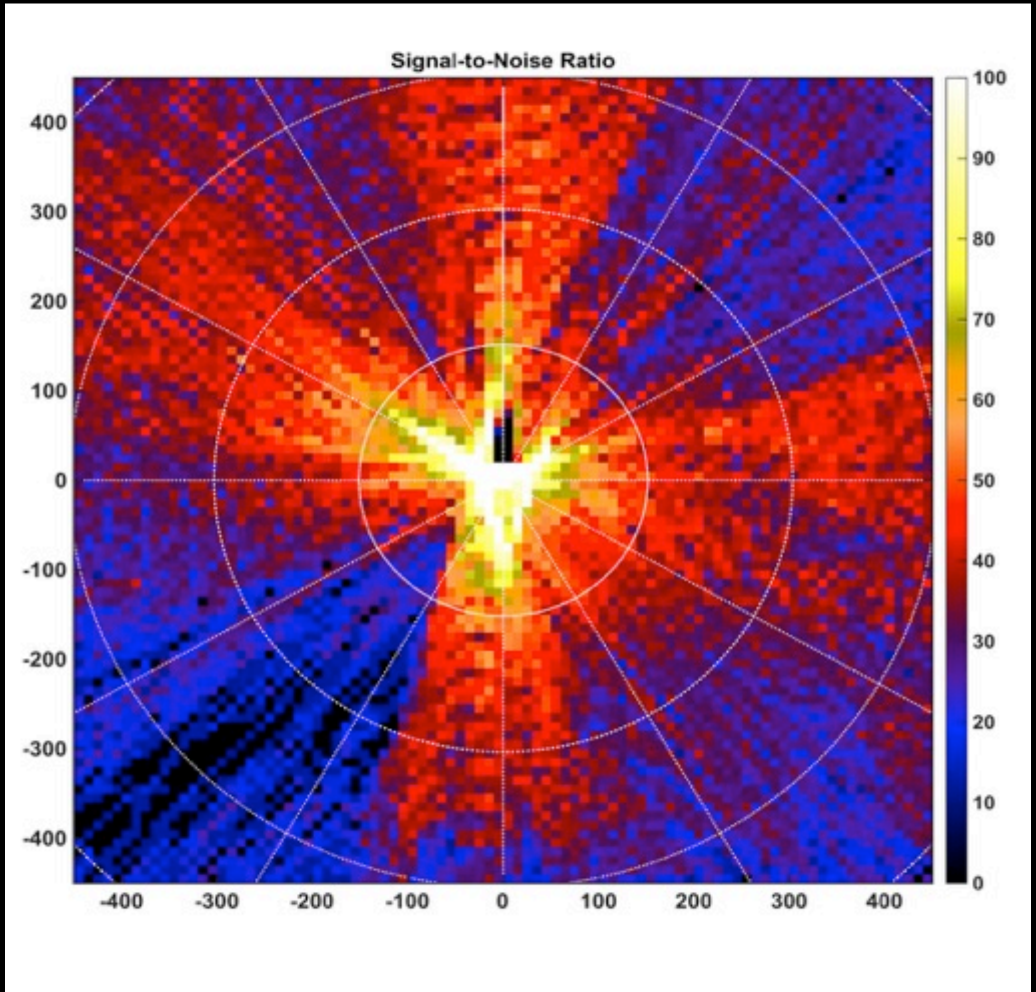
- Independent analysis
- Models need to verified and correlated with LunaH-Map team models and designs
- Models do not include energy-angle dependence of the detector
- Assumes 100cm^2 for epithermal neutrons (200cm^2 available)
- Assumes 141 science passes over the South Pole



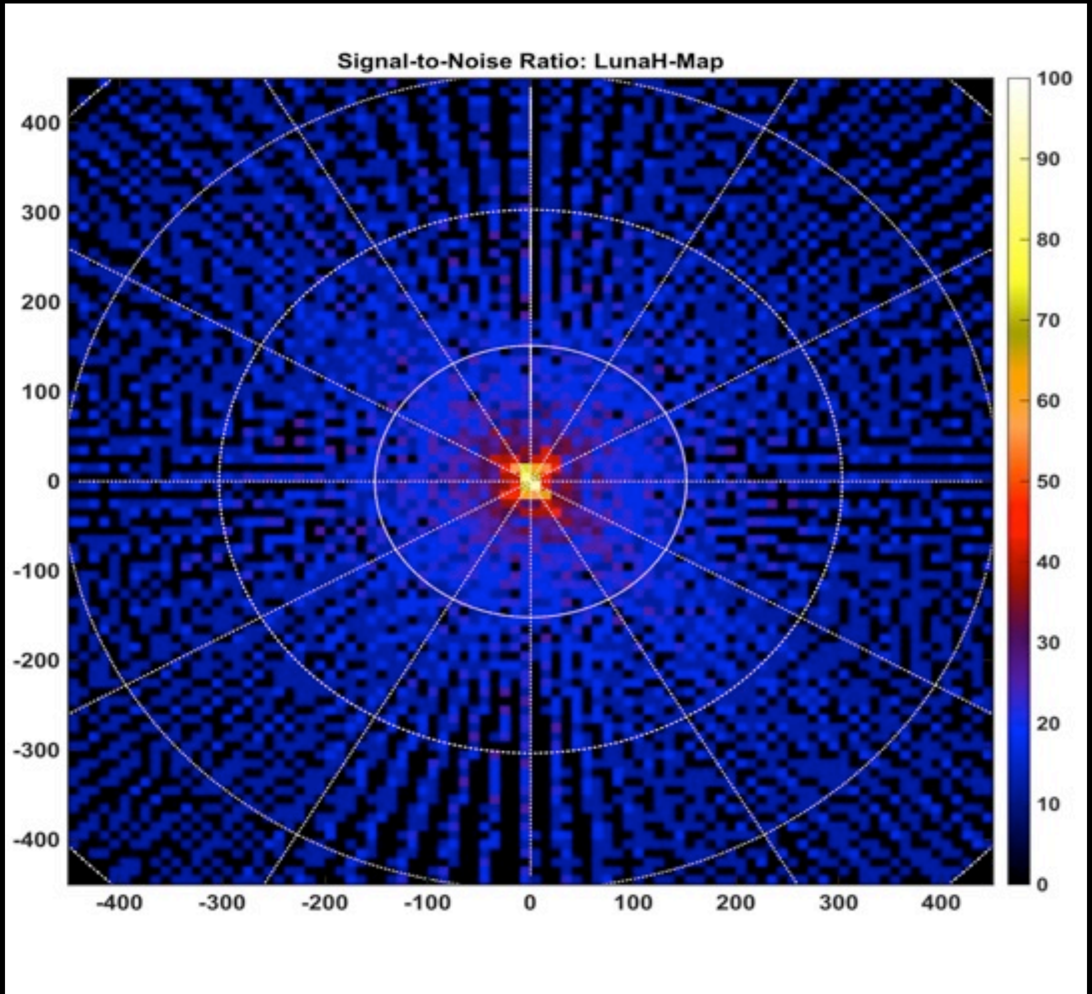
LunaH-Map Altitude Map over South Pole

***Independent Analysis of LunaH-Map Detection Capabilities by Rick Elphic**

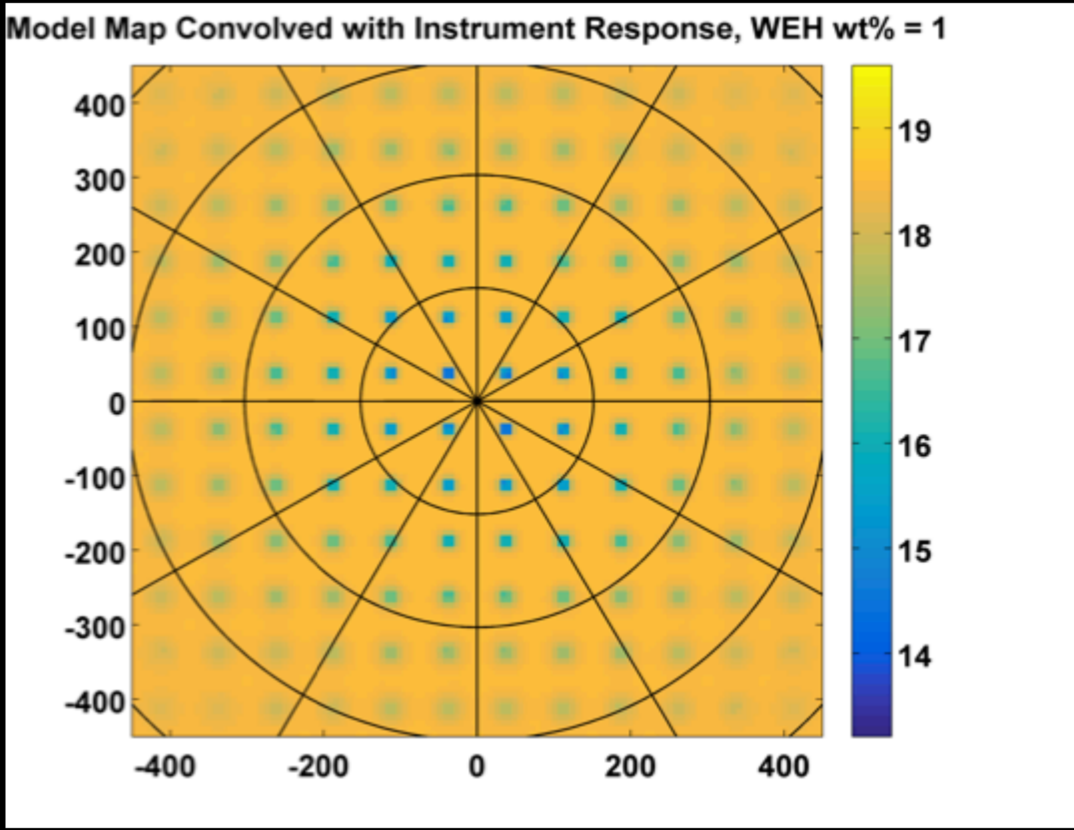
LPNS Raw Binned SNR in 10 km Bin
Altitude < 35 km

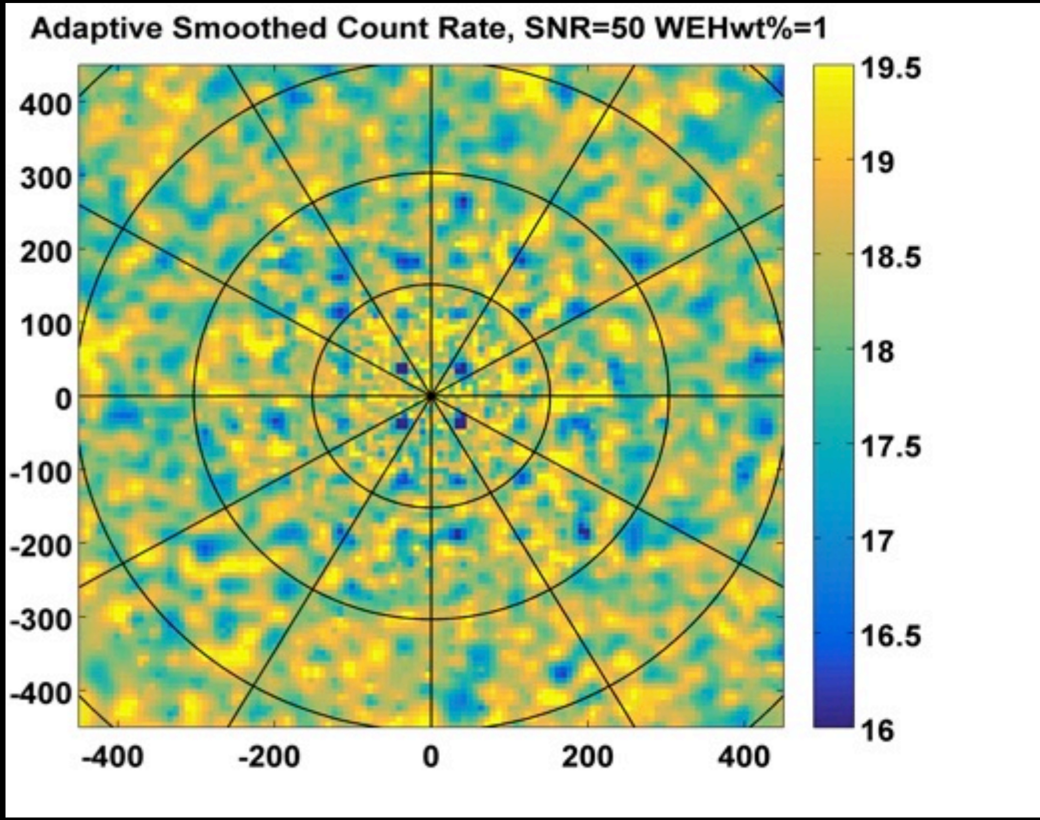


LunaH-Map Binned SNR in 10 km Bin



***Independent Analysis of LunaH-Map Detection Capabilities**



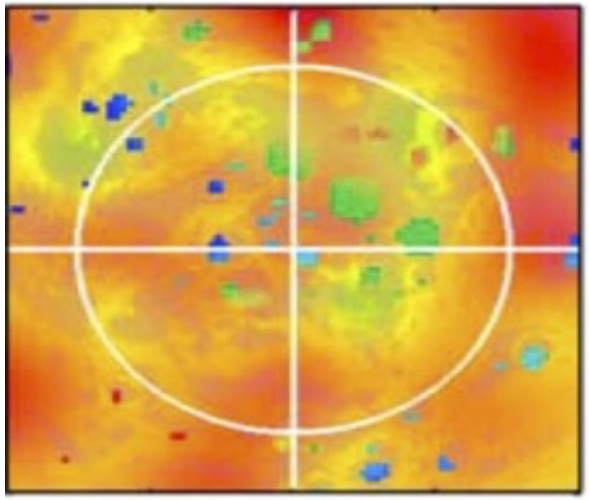


15km^2, 1 wt.% WEH “spots”

***Independent Analysis of LunaH-Map Detection Capabilities**

LunaH-Map Science Goals

Evaluate and constrain uniformity of bulk hydrogen abundance at the lunar south pole



Using Shackleton crater as example:

- Pixon reconstruction of LPNS data predicts about 0.6% WEH (600 ppm) uniformly distributed within Shackleton
- PSR area = 200 km^2, or approximately 15 km across

Design of Mini-NS and LunaH-Map:

- The Mini-NS will be designed to detect a hydrogen abundance of 0.6% WEH (600 ppm) +/- 120 ppm with a spatial footprint <= 15 km x 15km (>85S within 2-month nominal mission)
- The trajectory and mission design will allow Mini-NS to produce maps at spatial scales of <= 15 x 15 km (orbital altitude of <= 10km). Counts will be binned once per second

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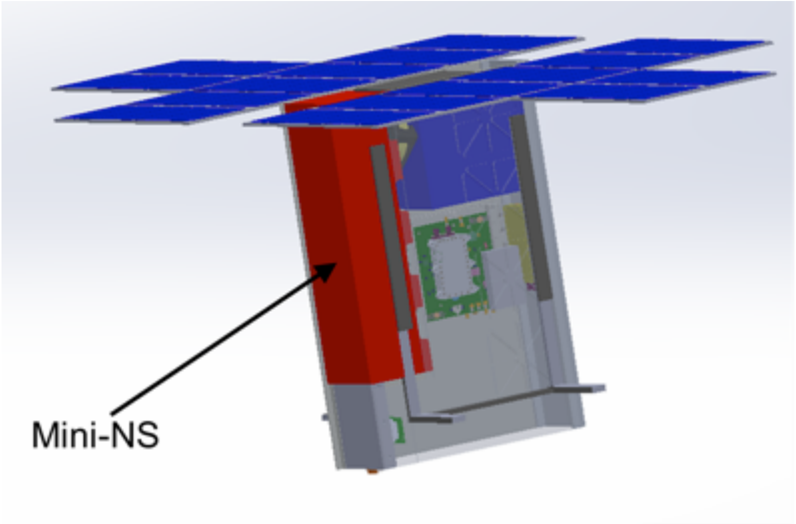
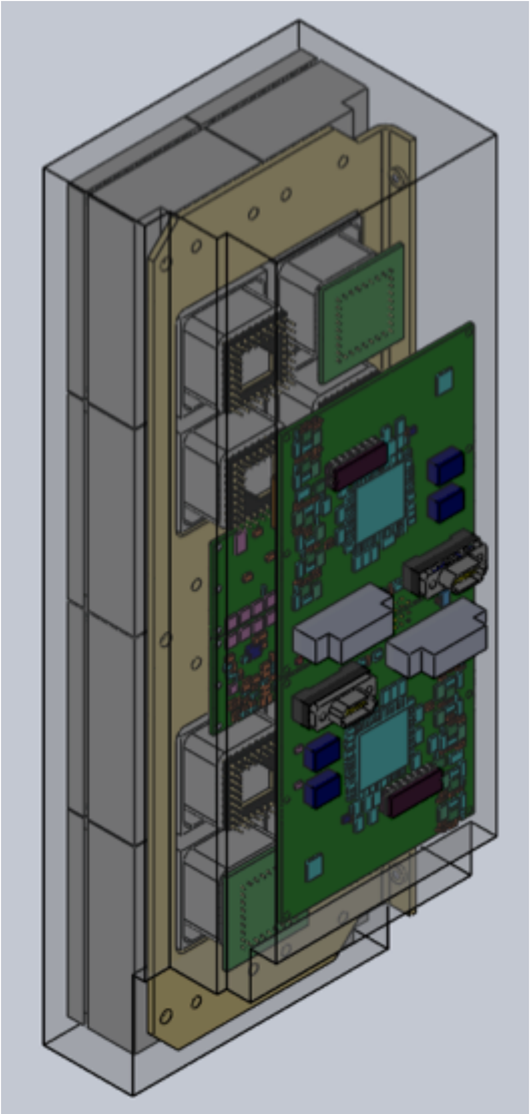
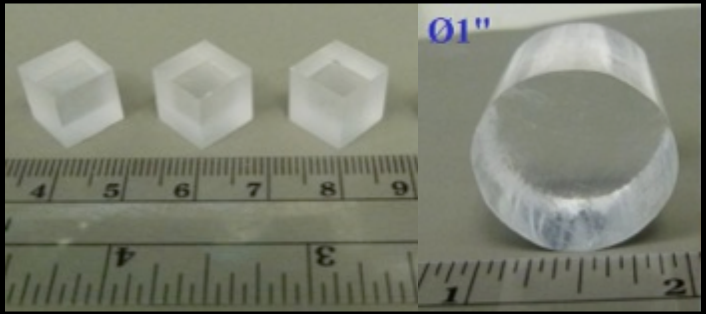
Science Instrument - Mini-NS

- Two Detectors
  - Four modules per detector
  - Each module consists of a neutron sensitive material optically coupled to a photomultiplier tube.
  - Front end electronics and signal processing.

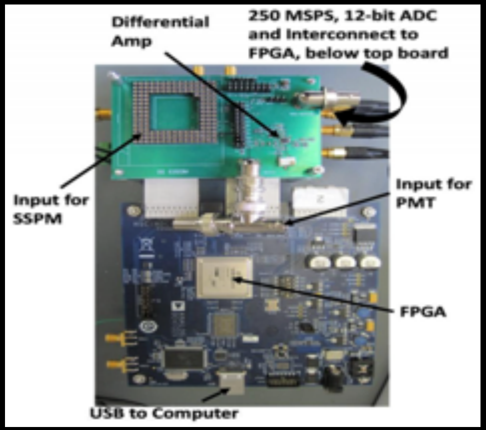




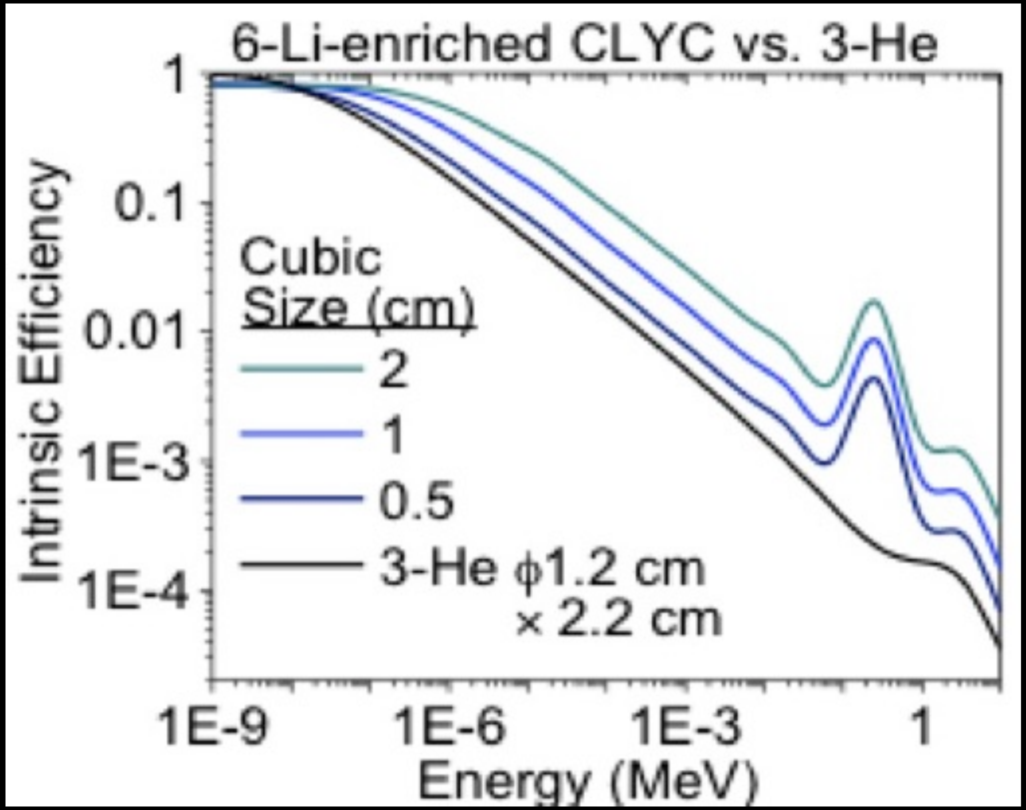
Mini-NS: CLYC Scintillator



CLYC can be grown into a variety of shapes and sizes. Has been rad (~200 MeV and very high dose rates >50 rad/s), vacuum and pressure tested. Can operate at -40C.



DAQ system developed for NASA SBIR/STTR



Comparison of CLYC to ^{3}He efficiency. CLYC shows a greater efficiency above 0.01 eV, saturating at 80%.

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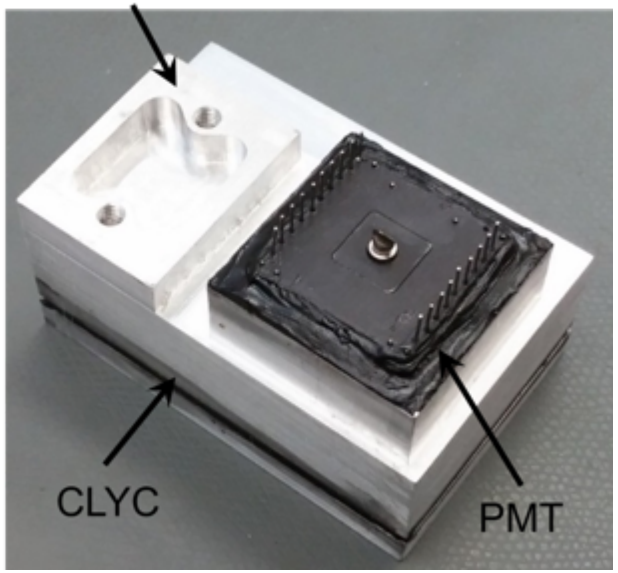
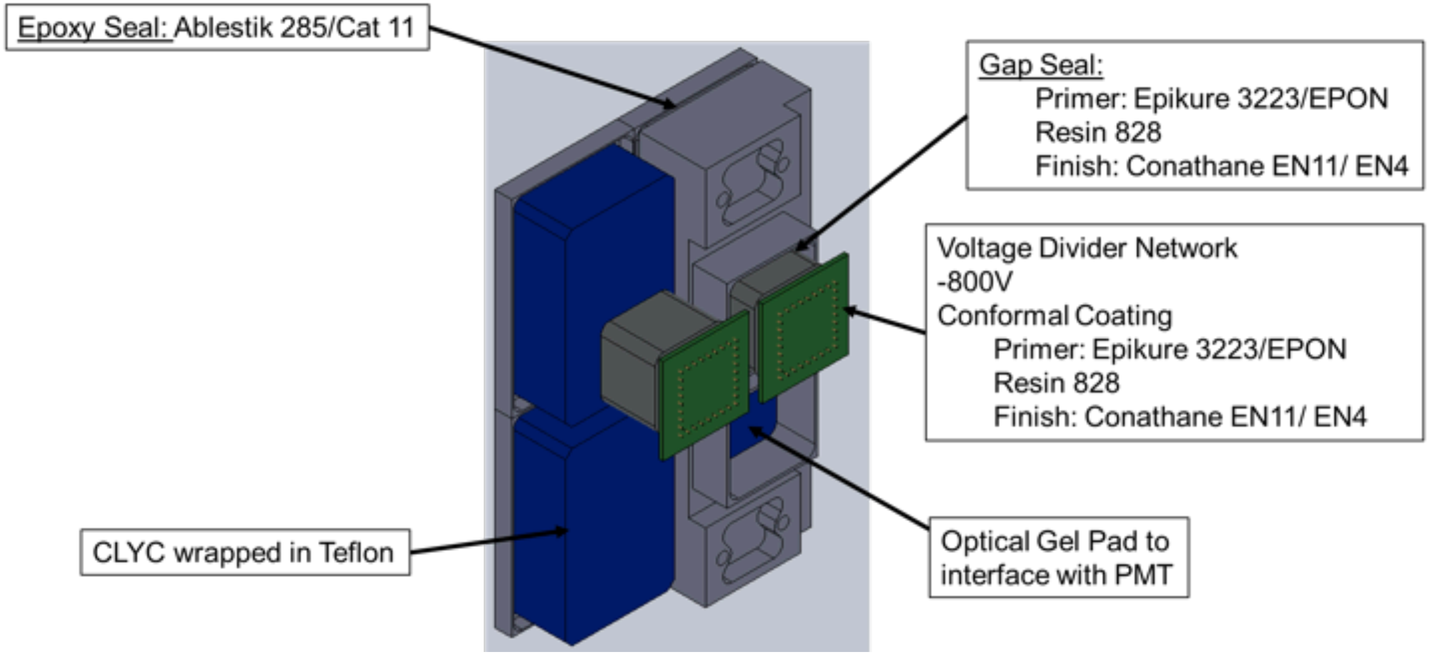
Mechanical Design: Modules

- Low-outgassing epoxies and encapsulants are used to seal the modules
- Thermal cycling and some low vacuum testing indicate that the package will remain sealed

Heat conduit





3. Mission/Spacecraft Design

The LunaH-Map Mission

Trajectory Design: Deployment to Lunar Capture

<u>TRAJECTORY SEQUENCE</u>

A) Launch / TLI → **Oct 7, 2018 {UTCG}**

B) Deployment → 8.6 hrs after TLI (**Oct 8, 2018**)

C) 1st thrust segment begins **24 hrs** after deployment
{3.7 days of +X thrusting begins **Oct. 9, 2018**}

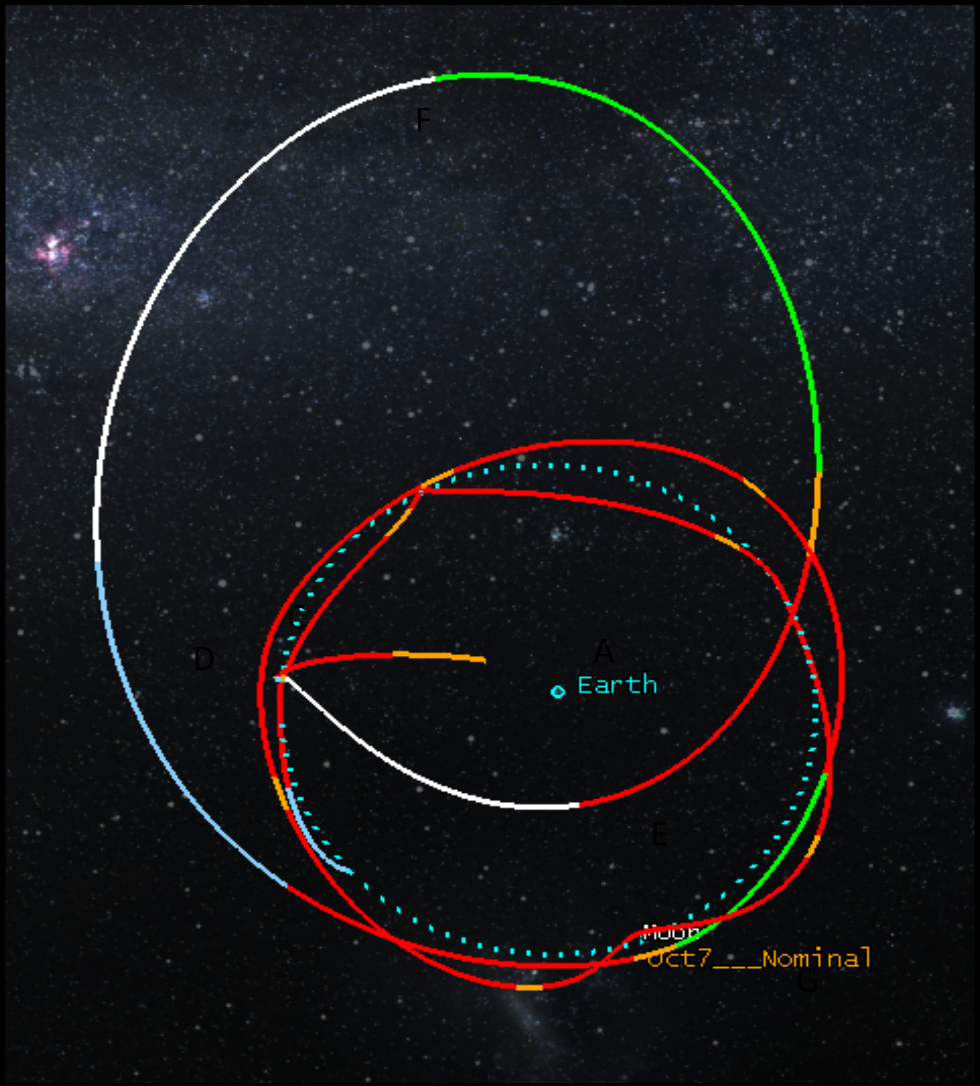
D) Lunar Flyby → L+ 5.8 days, **Oct. 13, 2018**

E) Post flyby thrust segment in anti-velocity direction starts at perigee (175,000 km altitude)
{4.2 days of thrusting begins **Oct. 16, 2018**}

F) Apogee → 1 million km altitude (**Nov. 12, 2018**)

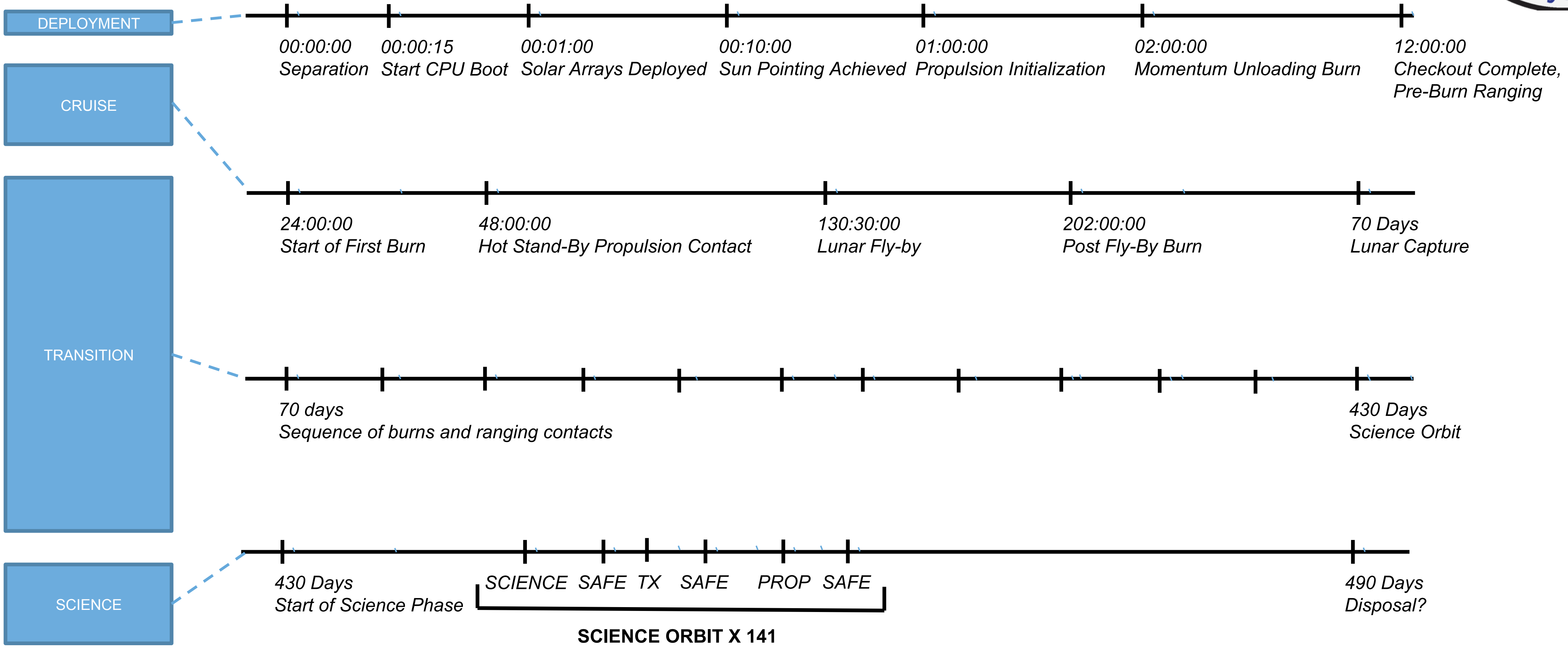
*** <u>**NO ECLIPSES OBSERVED during transfer**</u> ***

G) Lunar Capture → **L+ 70 days** (***Dec. 16, 2018***)
< 0.07 kg prop burned to lunar capture



Earth-centered, Earth inertial frame

Mission Timeline



Science Phase

141 consecutive science orbits with periodic maneuvers centered at apolune to control the perilune height above the lunar terrain

Science Orbit Sequence

Maximum Thrust Duration ~ 5.3 hours

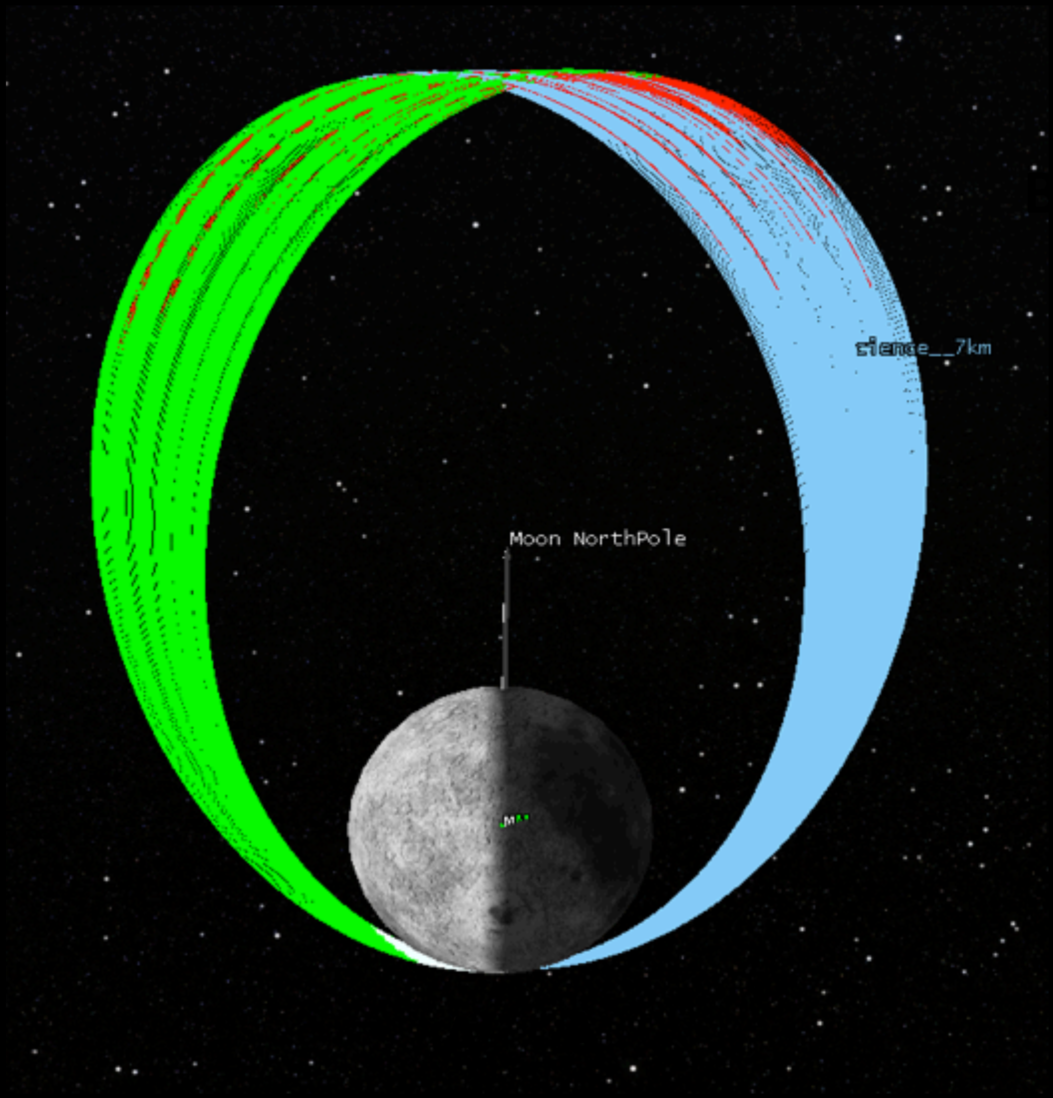
A) Science Measurement (t0)
B) Single Thrust arc begins (t0+ 2.4 hrs)
C) Single Thrust arc ends (t0+ 7.7 hrs)

repeat

A') Science Measurement (t0+ 10hrs)

Science Orbit Parameters

* Omega = 280 deg {center perilune drift on south pole}
* Inclination = 90 deg
* RAAN = 90 deg
* Apolune Altitude = 7,500 km



141 Science Orbits shown in Moon inertial frame

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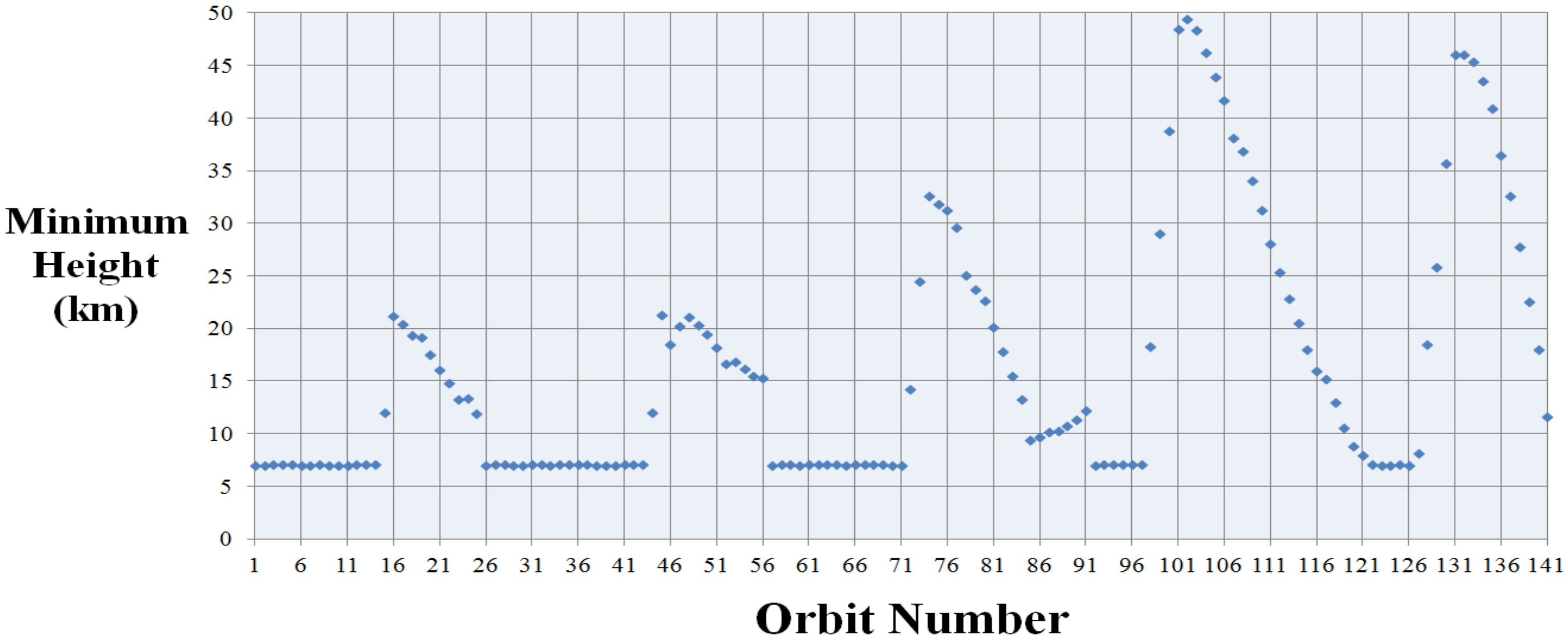
Minimum Height Above Terrain for all 141 Science Orbits



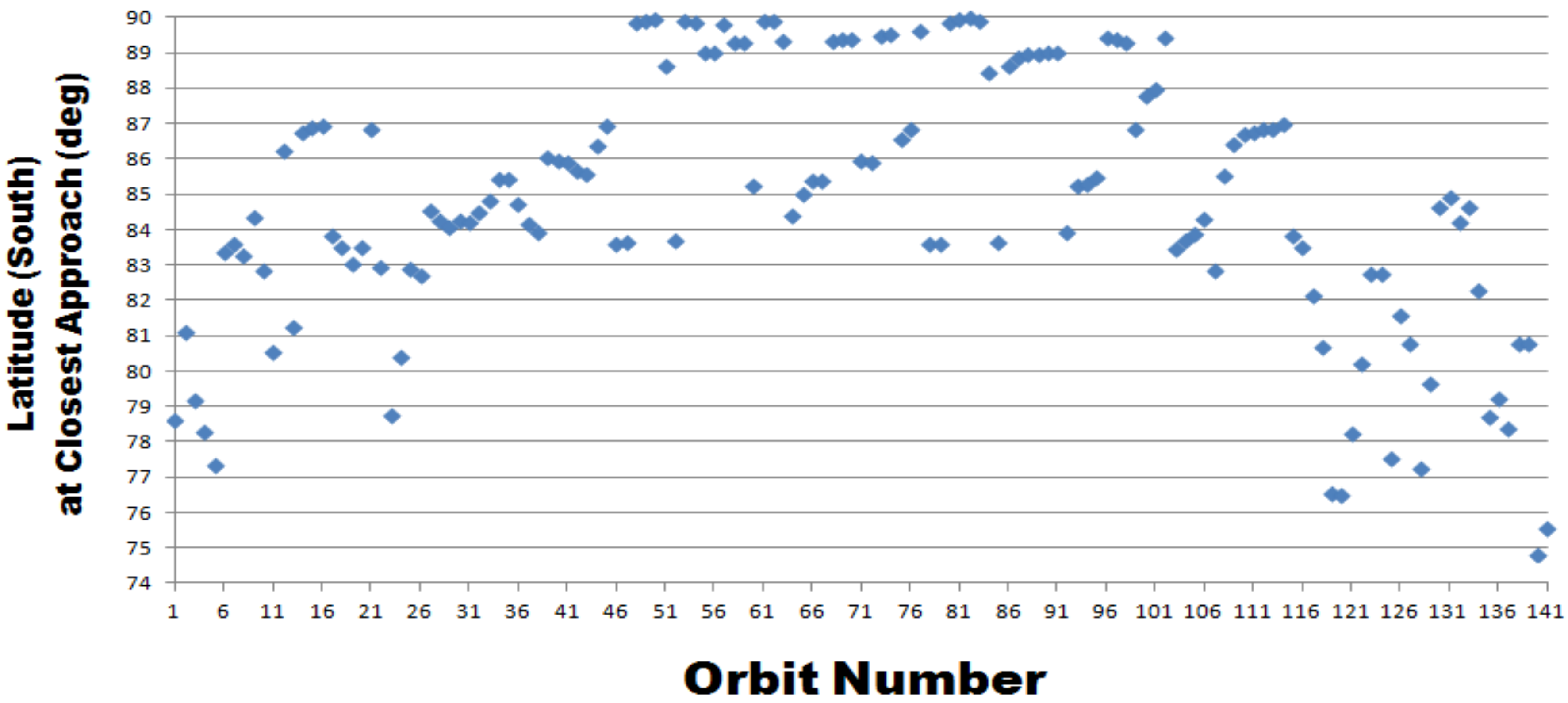
Statistics:

Minimum Height Above Terrain = 7 km
Average (mean) height above terrain = 16.6 km
Maximum height above terrain = 49 km
Controlled Orbits = 73 of 141 {52%}
Boost Maneuver Orbits = 15 of 141 {11%}
Coast Orbits = 68 of 141 {48%}

Maximum Consecutive Controlled Orbits = 21
Minimum Consecutive Controlled Orbits = 10

Maximum Consecutive COAST orbits = 21
* Minimum Consecutive COAST orbits = 8
***orbit #127 is a coast orbit, outlier**

Science Orbit: Lunar Latitude at Close-Approach



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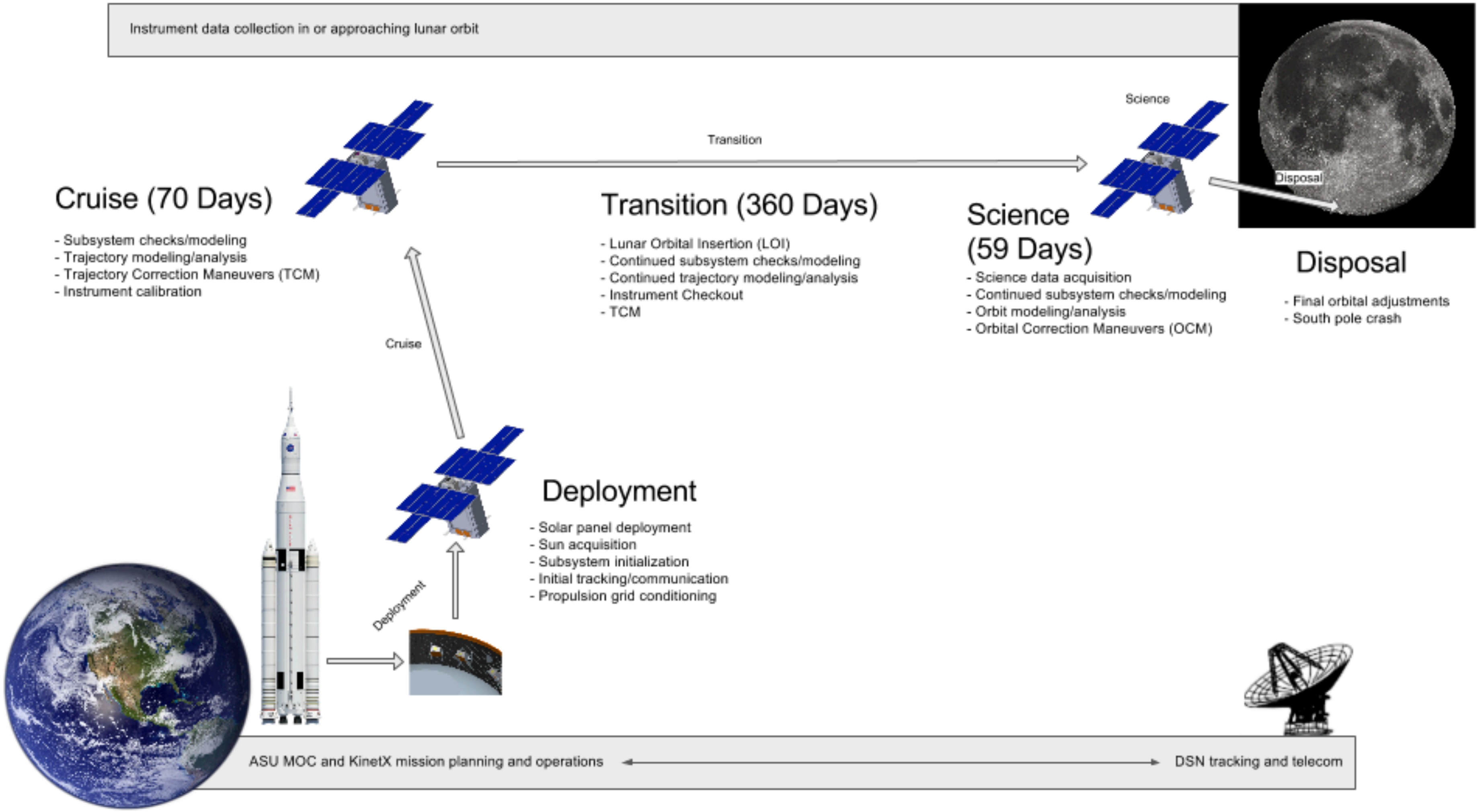
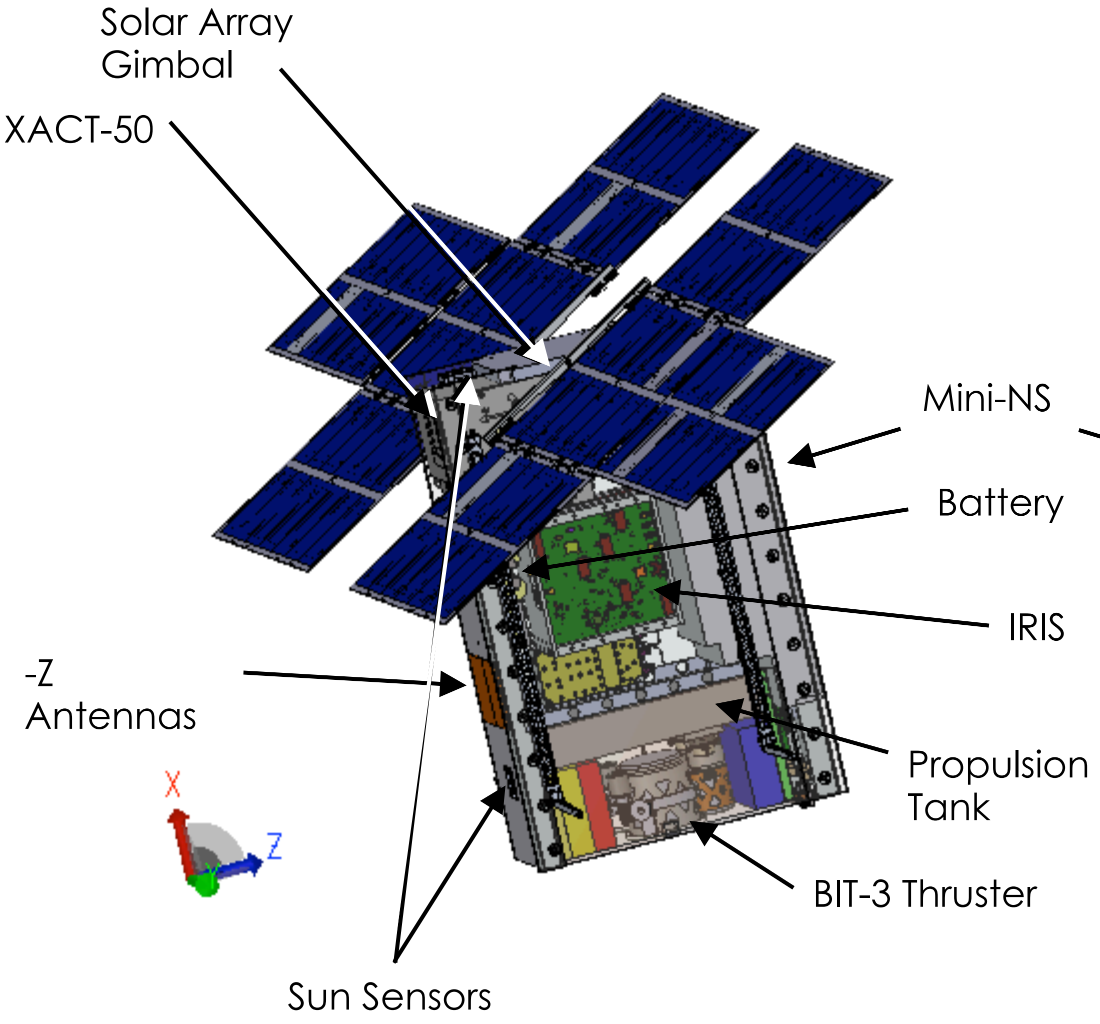
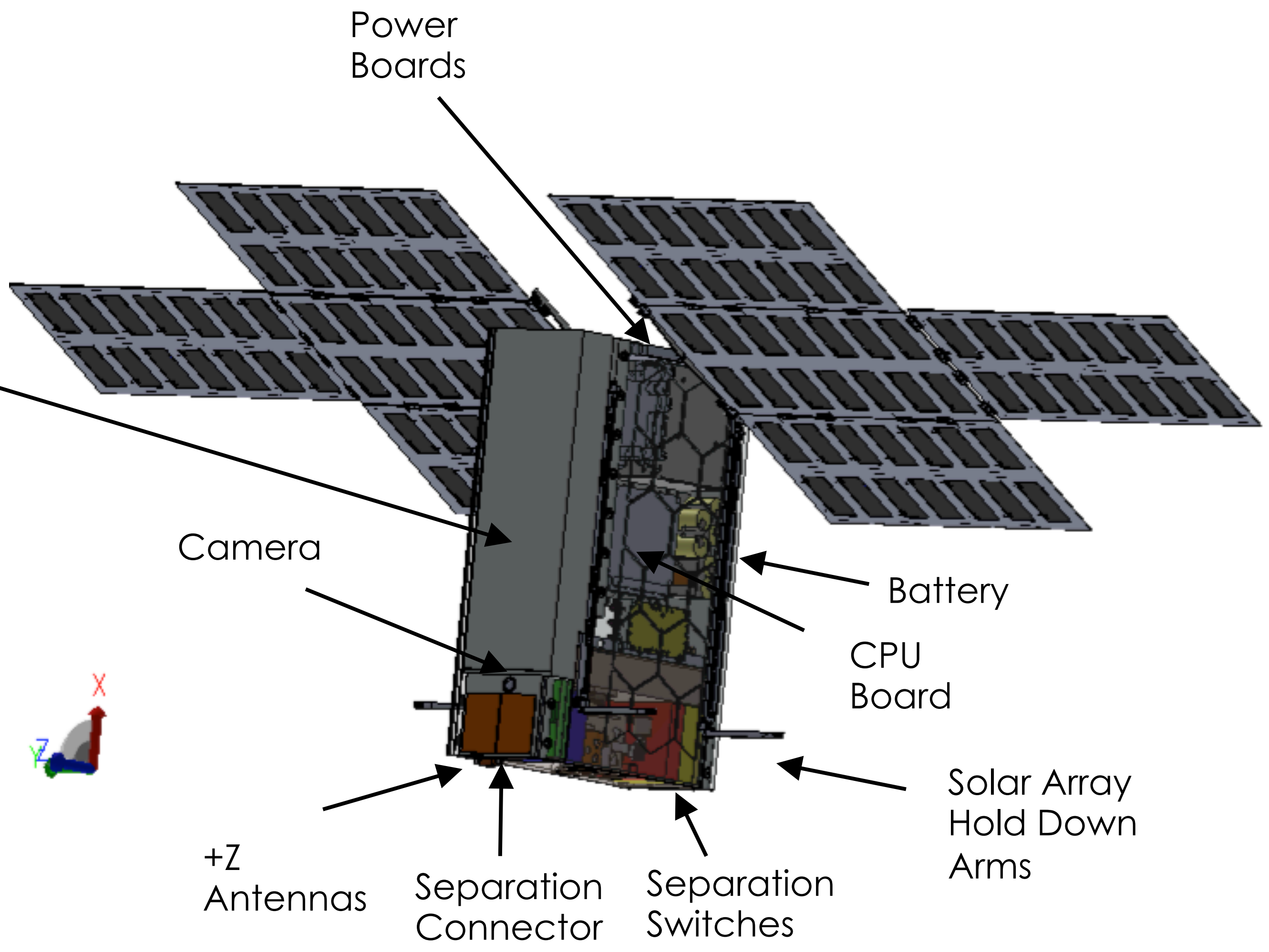
Concept of Operations



Spacecraft Layout





4. Project Status

The LunaH-Map Mission

Project Status

- Selected in late August, 2015
- Milestones in YR1

Accomplishment	Status	Date
Initial Accommodation Audit (IAA)	Complete	12/7/15
Delta IAA	Complete	3/4/16
Systems Requirements Review	Complete	4/8/16
Flat sat development start	Complete	5/27/16
Phase 1 Flight Safety Review	Complete	6/21/16
PDR for Subcontractors	Complete	7/25/16
Preliminary Design Review	Complete	7/25/16

- CDR early 2017
- Launch late-2018 on SLS EM-1

5. Impact of Small Satellites on Planetary Science

- SIMPLEx requires new solutions to address questions in planetary science
    - Targeted science mission, shorter schedules, smaller teams, more iteration, collaboration
    - LunaH-Map combines a high-heritage technique in planetary science with new detector materials (developed through NASA SBIR/STTR)
    - Many small business partnerships
    - LunaH-Map is University-led with many small businesses partners serving key roles.
    - Multiple missions on the same launch is critical! Collaboration on development is important for every mission’s success.

To the Moon!